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Research Article

Improving strawberry fruit quality through breeding: cultivar performance and biochemical diversity

Monica STURZEANU[1], Oana HERA[1*], Mădălina MILITARU[1], Loredana E. VÎJAN[2*]

*[1]Research Institute for Fruit Growing Pitesti, 402 Mărului Street, Pitești, Argeș, 117450, Romania; sturzeanu1980monica@yahoo.it; oana.hera@yahoo.com (*corresponding author); madamilitaru77@yahoo.com*
*[2]National University of Science and Technology Politehnica Bucharest, Piteşti University Centre, 1 Targu din Vale Street, Pitesti, 110040, Romania; loredana.vijan@upb.ro (*corresponding author)*

Abstract

Strawberry (*Fragaria × ananassa Duch.*) breeding has a long tradition worldwide, driven by the need to combine high yields with superior fruit quality and resilience to environmental challenges. At the Research Institute for Fruit Growing Pitești, Romania, breeding activities began in the 1980s and expanded significantly in the 21st century. The first registered cultivar, 'Premial', released in 1989, remains the dominant variety grown in Romania. The program is based on traditional cross-pollination and recurrent field selection, in which new seedlings are rapidly evaluated and the best individuals are advanced as parents for the next generation. Breeding objectives target disease resistance, early and consistent yields, and plant architecture that facilitates harvesting. Market preferences emphasize uniform fruit size, colour and shape, while consumers especially value flavour. To provide a reference for future breeding, this study analyzed seven cultivars released between 1980 and 2019. Pedigree data were examined to identify the most influential parental genotypes, and the genetic contribution of ancestral parents was estimated for each cultivar. Agronomic performance, yield and fruit quality were also evaluated. Among the tested cultivars, 'Ireal' and 'Sarom' showed the best overall performance for yield and fruit quality, while 'Coral' was outstanding for sweetness (11.50 °Brix). 'Sarom' also exhibited large fruit size (24.20 g/fruit) and high firmness (37.73 N), making it particularly suitable for storage and commercial distribution. These findings highlight the potential of newly developed cultivars, especially 'Sarom' and 'Ireal', for cultivation under local conditions and as valuable resources for future breeding programs.

Keywords: biochemical diversity; cultivar evaluation; fruit quality; *Fragaria × ananassa*; pedigree analysis; yield performance

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Introduction

Genus *Fragaria* consists of several species, ranging from diploid to octoploid, and including various types of sex determination (Akiyama *et al*., 2001). The strawberry (*Fragaria* × *ananassa*) is a hybrid obtained by crossing two species of wild strawberries from different regions of the world (Hancock and Luby, 1993). Emerging in the mid-1700s from the crossbreeding of two wild octoploid species, *Fragaria chiloensis* and *Fragaria virginiana*, in Versailles, France, it has since become one of the most widely cultivated fruits globally (Marta *et al*., 2004). Both *F. chiloensis* and *F. virginiana* are predominantly octoploid in the wild (Darrow, 1966) and this contributes to *F. x ananassa* clones being highly heterozygous (Scott and Lawrence, 1975). However, inbreeding of *F. x ananassa* clones (Morrow and Darrow, 1952) results in rapid loss of vigour (Powers, 1944), yield, and fruit size (Morrow and Darrow, 1941).

In the context of sustainable agricultural development, the introduction of new strawberry cultivars is crucial, as it leads to the replacement of existing varieties with those that exhibit improved characteristics in terms of adaptability, management, and quality (Hummer and Hancock, 2009). As a result, farmers benefit from plants that are more productive, with superior quality traits, disease resistance and significant economic benefits (Tanaka *et al*., 1999; Khoury *et al*., 2022; Prochnow *et al*., 2025). Genetic improvement programs are focused on developing cultivars that are easy to manage (small, upright plants), resistant to pests and diseases, high-yielding, early-bearing, and capable of producing large, attractive, and sweet fruits (Rios, 2007; Antunes *et al*., 2010).

Growing strawberries has been experiencing significant global growth, driven by innovations in advanced breeding and biotechnology projects, as well as research that provides a deeper understanding of plant physiology (Mezzetti, 2013). Among these programs and in germplasm repositories, there is still considerable variation available in traits of economic interest (Chandler *et al*., 2012). These findings contribute to the development of modern and efficient cultivation systems. Genetic resources remain necessary for breeding efforts, now enhanced by advancements in genomics and molecular technologies (Mezzetti, 2013).

Currently, several prominent research groups are at the forefront of the development and application of these technologies. At the same time, an increasing number of emerging companies are demonstrating their ability to introduce significant innovations with considerable local and global impact. These initiatives are supported by major public research projects, including those with an international scope, but collaboration between researchers and companies is crucial for translating scientific results into practical and innovative solutions. The primary goal is to expand strawberry cultivation by developing modern varieties that can easily adapt to diverse cultivation media and methods (open fields, greenhouses, or suspended systems). Simultaneously, efforts are focused on reducing environmental impact while improving the safety and quality of strawberries for consumers (Neri *et al*., 2012; Faedi and Baruzzi, 2016; Lyzhin *et al*., 2024).

Given the continuous progress in strawberry breeding and the growing need for high-performance varieties, this study aims to evaluate the agronomic behaviour, fruit quality, and adaptability of a range of strawberry cultivars - some well-established and others newly developed - under specific cultivation conditions. In a context where varietal selection is becoming increasingly complex, our research seeks to identify genotypes that combine high productivity, ease of management, disease resistance, and commercially attractive fruit characteristics (Giovanetti, 2024). The experimental design has been tailored to simulate realistic production environments, analyzing genotype-environment interactions and key physiological traits. Through this approach, we hope to contribute to the selection of varieties better suited to modern agricultural and commercial demands, providing a valuable tool for growers, breeders, and stakeholders in the horticultural sector. In agronomic crops and forestry, modern quantitative genetic approaches have become standard tools (Smith *et al*., 2005). Particular focus is given to analysing data from multi-environment trials (Bernardo, 2020) and selection processes (Shalizi and Isik, 2019).

Worldwide, the total cultivated area for strawberries in 2023 was 434,911 hectares, generating a production of approximately 10.5 million tons (Table 1). The global average yield per hectare was about 24.07 tons. Europe, with 151,081.2 hectares cultivated and a production of 1,778,614.1 tons, shows significant diversity in yield per hectare. Countries like Spain, with 7,310 hectares and a production of 329,280 tons, achieve an outstanding yield of 45.1 tons per hectare, thanks to favourable climate conditions and highly efficient cultivation techniques. Conversely, other European countries, such as Poland and Romania, have much lower yields, likely due to a combination of factors such as less favourable land, less advanced agricultural technology, and more challenging climate conditions. In Romania, in 2023, the cultivated area for strawberries was 2,840 hectares, with a total production of 20,640 tons.

Table 1. The strawberry area harvested and production, 2023 (Source FAOSTAT)

Continent/ Country	**Area harvested (ha)**	**Production (t ha $^{-1}$)**
World	434,911	10,485,454.06
America	54,219	41,706
USA	22,986	1,250,100
Asia	197,890	5,359,686.58
China	156,316	4,216,716.93
Japan	4,763	158,467.82
Egypt	21,033	731,114.93
Turkey	21,984	676,818
Africa	26,007	892,690.8
Egypt	21,033	731,114.93
Europe	151,081.2	1,778,614.1
Spain	7,310	329,280
Poland	30,000	194,500
Italy	4,350	119,920
Romania	2,840	20,640

Over the decades, research on strawberry hybridization and breeding continued in Romania. In 1956, the first genetic breeding works began at the Horticultural Research Station Cluj (Cociu *et al*., 1999), followed by extensive research programs in other locations such as the Horticultural Research Station Satu Mare (1982) and the Research Institute for Fruit Growing Pitesti (1989). These initiatives aimed to improve the fruit's quality and its adaptability to various climatic conditions specific to Romania.

Strawberry breeding combines natural genetic diversity with directed hybridization. From the initial hybridization experiments in the 18th century to the extensive research conducted in the 20th and 21st centuries, the evolution of the strawberry is a story of continuous improvement. Today, the modern strawberry stands as a result of centuries of hard work, innovation, and adaptation, meeting the demands of consumers and the agricultural industry worldwide. As science continues to advance, the future of strawberry breeding holds exciting potential, ensuring that these beloved fruits will remain a vital part of our lives for generations to come (Braniște *et al*., 2007)

The Romanian research methodology was based on directed and controlled hybridization. The best traits were selected from various species and cultivars to produce varieties capable of thriving in the local environment (Hera, 2024). This ongoing work in Romania has played a crucial role in increasing genetic diversity, as well as enhancing productivity and quality. This methodology involves directed and controlled hybridisation using the rich collection from Pitesti (Braniște *et al*., 2007; Temocico and Sturzeanu, 2018). This collection comprises seven cultivars (Figure 1), which are listed in the EURISCO catalogue: 'Premial' (1989), 'Coral' (1993), 'Real' (1998), 'Magic' (1998), 'Floral' (2004), 'Sarom' (2018) and 'Ireal' (2019).

Figure 1. The Romanian strawberry cultivars: 1 - 'Premial'; 2 - 'Coral'; 3 - 'Real'; 4 - 'Magic'; 5 - 'Floral'; 6 - 'Sarom'; 7 - 'Ireal'

Over the past century, the success of plant breeding has been associated with a reduction in the genetic diversity of superior plant germplasm (Zoratti *et al*., 2015; Hera, 2024). Research in this field has also centred on maximising yield and fruit size, improving disease resistance and transportability, and extending postharvest shelf life (Lado *et al*., 2010). The aim of this study was to evaluate the performance of Romanian cultivars in terms of yield, fruit quality, pedigree, and other agronomic traits, with the goal of identifying the most promising cultivars for enhancing agricultural practices and product quality in the region, using a combination of quantitative and qualitative methods.

Materials and Methods

The experiment was conducted at the Research Institute Growing Pitesti, located within the Small Fruits and Strawberry Department, in an experimental plot and, focused on several key factors such as total yield, fruit size, shape index, firmness, total titratable acidity (TTA), and total soluble solids (TSS).

Biological material

The experiment was set up during 2020-2025 at the Research Institute for Fruit Growing Pitești, Romania. The biological material was represented by 7 Romanian cultivars of strawberry: 'Coral' originated from the cross ('Sunrise × Gorella') × 'Early Glow'; 'Floral' originated from the cross 'Red Gauntlet × Irvine'; 'Ireal' originated from the cross 'Queen Elisa × Real'; 'Magic' originated from the cross 'Cardinal × MDUS 4044'; 'Premial' originated from 'NJ 306' (open pollination); 'Real' originated from the cross 'Premial × Brio'; 'Sarom' originated from the cross 'Mira × Real'. The cultivars were planted in an experimental plot with a planting in a randomized block design with three 10 plants replicates per variety in the open field.

The distance of planting was 0.3 × 1.2 m into medium-textured and heavy-clay soils, that had medium to low humus content, covered by black plastic mulch and the method of irrigation used drip.

The fertilization with chemical fertilizers was based on agrochemical parameters analysed. Due to phosphorus and nitrogen deficiencies, NPK complex fertilizer was applied.

The pedigree networks of cultivated strawberry are extraordinarily complex, shaped by a long history of diverse hybridizations, directional breeding, gene flow, admixture, genetic bottlenecks, overlapping generations, and repeated crossings with shared ancestors (Figure 2, 3, 4 and 5). These ancestors have contributed unequally to the genetic diversity found in both heirloom and modern cultivars (Pincot *et al.*, 2021). Figures 2, 3, 4 and 5 show the genetic background of the seven Romanian strawberry varieties, highlighting the lineages and genetic links between various varieties.

Figure 2 demonstrates that 'Floral' is a genetic crossover variety, resulting from a combination of varieties with different origins (Scotland, California, America). Being the result of crossing several varieties, 'Floral' inherited characteristics of each of the varieties used as parents.

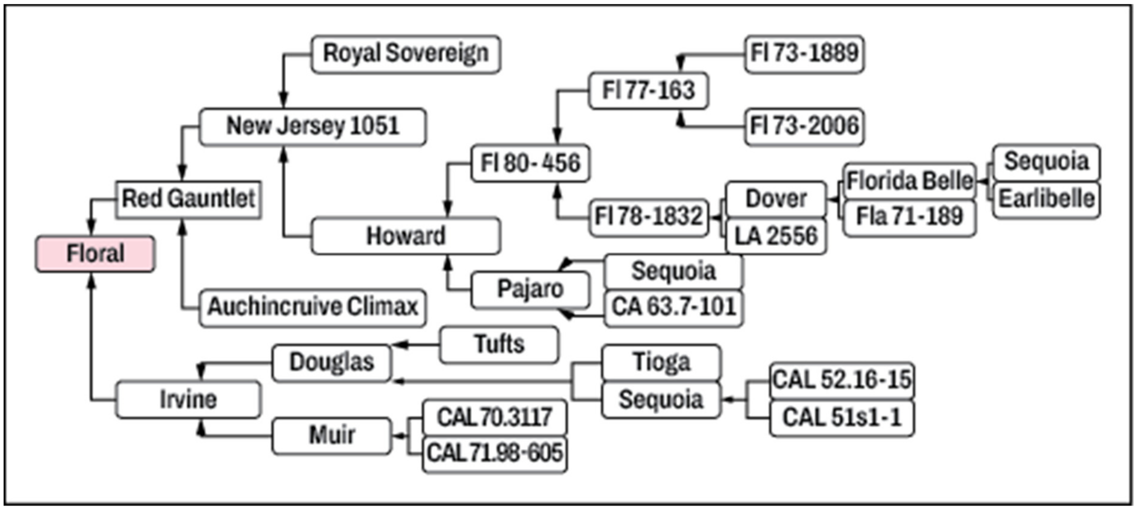

Figure 2. The pedigree construction of 'Floral' cultivar

Figure 3 demonstrates that 'Coral' is a crossover from 'Sunrise' and 'Gorella' and other varieties with different origins (Italy, America), as can be seen in the connections in the diagram.

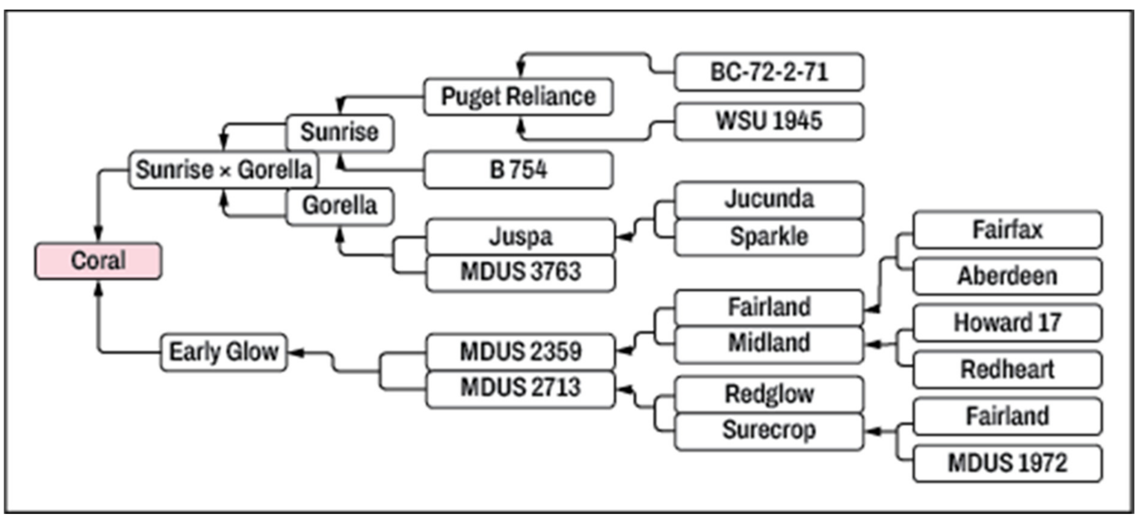

Figure 3. The pedigree construction of 'Coral' cultivar

Figure 4 demonstrates that 'Ireal' is a crossover from 'Real' and 'Queen Elisa', cultivars from Romania and Italy. As can be seen in the connections in the diagram, the origin of genitors is from Italy, America.

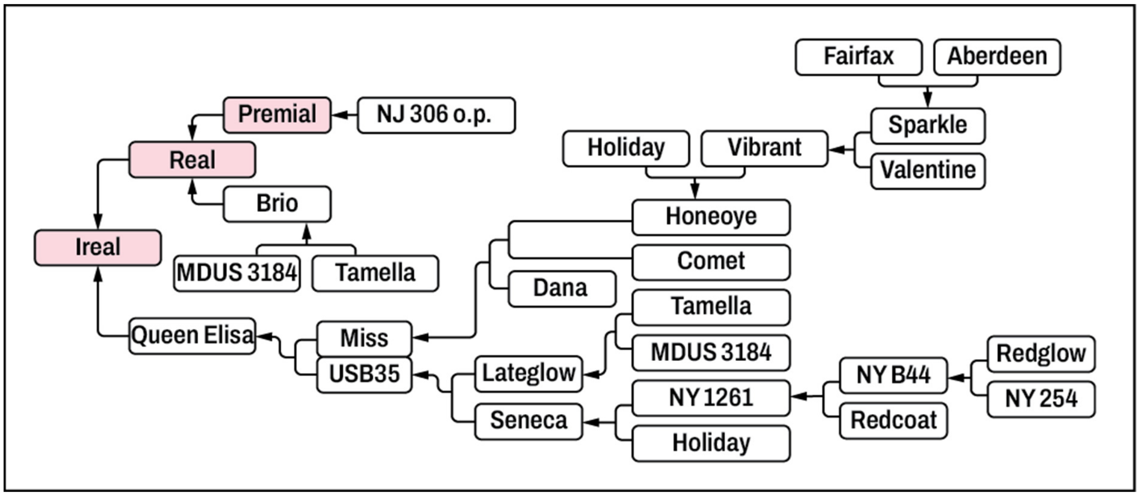

Figure 4. The pedigree construction of 'Ireal' and 'Real' cultivars

Figure 5 demonstrates that 'Sarom' is a cross between 'Honeoye' and 'Mira', and is related to other varieties such as 'Tioga' and 'Sunrise'. 'Magic' is a cross between 'Cardinal' and 'MDUS 4044'.

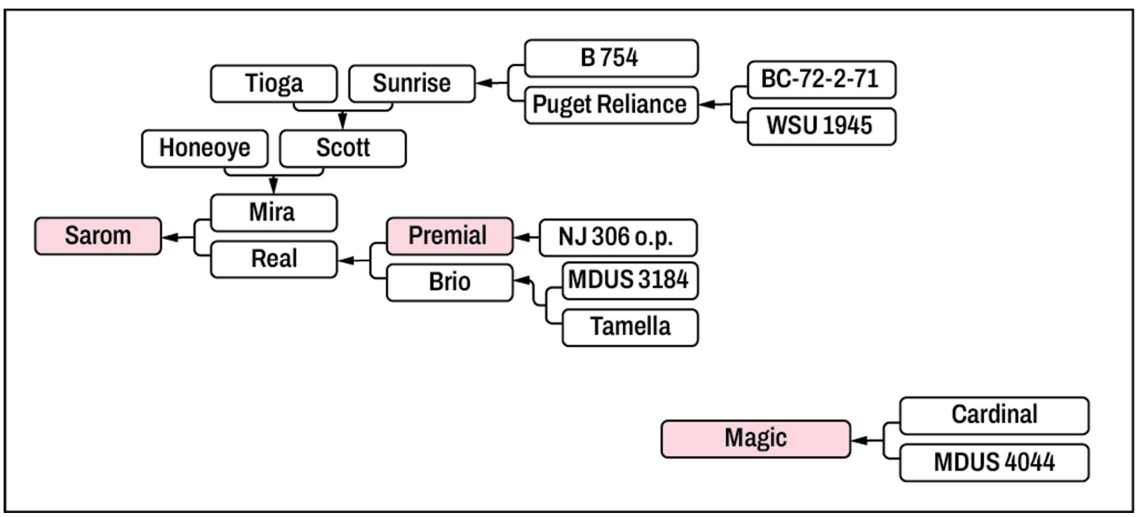

Figure 5. The pedigree construction of 'Sarom', 'Premial' and 'Magic' cultivars

Experimental procedures

In this experiment, the production per plant is determined by weighing the total yield produced by each plant (Feldmann *et al*., 2024). The size of the fruit was evaluated by determining the average weight. A sample of 50 fruits from 15 plants of each genotype was weighed, and the average weight per fruit was calculated.

Length and diameter of the fruit were measured using a digital calliper and the shape index (SI) was calculated. The SI is calculated by measuring the fruit's height and diameter, and then taking the ratio of these two dimensions (Tudor *et al*., 2014). Firmness was measured using a nondestructive penetrometer, which ensured that the fruit was not damaged during testing. The penetrometer used in this experiment, the Bareiss HPE II, has a measuring surface of 0.25 cm^2, providing a precise measurement of firmness.

Total titratable acidity (TTA) was determined using the titration method, a widely accepted procedure for measuring the acidity of fruit juice. Total soluble solids (TSS) content was measured using a refractometer, and the results were expressed in °Brix at 20 °C. Total sugar content (TSC) was determined by the method proposed by Vîjan *et al*. (2023), using 0.5 ml of an equimolecular mixture of aqueous extract and distilled water. Total polyphenol content (TPC) was determined according to the method proposed by Matić *et al*. (2017), using 0.5 ml of ethanolic extract for the analysis. Total flavonoid content (TFC) was determined in accordance with the method-ology proposed by Tudor-Radu *et al*. (2016), using 1 ml from ethanolic extract for the analysis. Total anthocyanin content (TAC) was determined by the pH differential method proposed by Lee *et al*. (2005) and modified by Hera *et al*. (2025), using 0.5 ml of ethanolic extract for analysis. The antioxidant activity was evaluated by measuring the radical scavenging capacity of DPPH free radicals, following the methodology proposed by Mazilu *et al*. (2022).

The colorimetric analysis provides a detailed insight into the visual quality of the strawberry cultivars. By analyzing the brightness value (L*), chroma index (C*), and hue angle (h^0), it can assess which cultivars have the brightest, most saturated, and most appealing colour.

Statistical analysis

The data collected from the experiments were subjected to rigorous statistical analysis. All analyses were performed in triplicate to ensure reliability and accuracy. The data were reported as mean ± standard deviation (SD) to provide a clear representation of the results. The statistical tools were performed using the SPSS 26.0 software, such as one-way analysis of variance (ANOVA) and two-way ANOVA, along with Duncan's multiple range test, were used to compare the results and identify significant differences between the various cultivars, with an error probability ($p \leq 0.05$).

Results and Discussion

Table 2 shows the values for various fruit parameters of seven strawberry cultivars. The highest production was recorded for the 'Ireal' (0.69 kg $plant^{-1}$) and the 'Sarom' (0.60 kg $plant^{-1}$), which showed strong yield performance compared to the other cultivars. 'Floral', on the other hand, exhibited the lowest yield (0.37 kg $plant^{-1}$), indicating that it may not be as productive under the conditions of this study. For average fruit weight, the highest fruit weight was recorded by 'Sarom' cv (24.20 g) significantly heavier than the other cultivars. The cultivars 'Premial', 'Coral', 'Real', and 'Magic' all showed similar berry weights, around 17-18 grams per fruit. Findings from Temocico *et al*. (2019) show that the study also recorded similar patterns, where some cultivars showed larger fruits while others were more uniform in size but smaller. The 'Real' had the largest size index (1.51), meaning that its fruits are relatively larger compared to their weight, contributing to its overall fruit size. In contrast, the 'Magic' had the smallest size index (1.02), suggesting that its fruits, while not as large, might be denser.

Table 2. Fruit parameters of strawberry cultivars

Cultivar	Production (kg $plant^{-1}$)	Weight (g $fruit^{-1}$)	Size index	Firmness (N)	pH	TSS (°Brix)
'Premial'	0.47±0.08 cd*	18.33±1.04 b	1.07±0.02 cd	17.10±1.87 c	3.40±0.10 abc	10.33±0.72 b
'Coral'	0.42±0.02 d	17.50±0.10 b	1.43±0.11 ab	20.98±1.16 bc	3.37±0.06 bc	11.50±0.20 a
'Real'	0.55±0.07 bc	17.63±2.25 b	1.51±0.05 a	16.83±2.42 c	3.27±0.15 c	8.97±0.31 c
'Magic'	0.44±0.05 cd	18.17±0.76 b	1.02±0.12 d	18.20±3.49 bc	3.40±0.10 abc	7.90±0.10 d
'Floral'	0.37±0.02 d	17.10±0.33 b	1.36±0.02 b	24.10±2.91b	3.47±0.15 abc	8.70±0.26 cd
'Sarom'	0.60±0.09 ab	24.20±0.87 a	1.32±0.10 b	37.73±4.48 a	3.77±0.19 a	10.07±0.84 b
'Ireal'	0.69±0.06 a	17.10±0.33 a	1.18±0.05 c	36.03±6.01a	3.72±0.41ab	9.97±0.67 b

*Differences between the means shown with the different letters in the same column are significant at the $p < 0.05$ level

The firmness is an important factor in strawberry quality, affecting both shelf life and taste. The 'Sarom' had the highest firmness value (37.73 N), indicating a firmer fruit. The 'Real' had the lowest firmness value (16.83 N), meaning its fruits are softer. Significant differences in firmness were observed between cultivars, confirming that this is a variable trait with potential implications for fruit quality. pH values ranged from 3.27 ('Real') to 3.77 ('Sarom'), showing slight variations in acidity across the cultivars. 'Coral' had the highest TSS content (11.50^{0}Brix), suggesting that its fruits are the sweetest. In contrast, 'Magic' exhibited the lowest TSS content (7.90^{0}Brix), indicating that it may be less sweet, which could influence its flavour profile and consumer preference.

Biochemical Diversity of Strawberry Cultivars: A Comparative Analysis

The data presented in Table 3 reveals significant biochemical diversity across the seven strawberry cultivars. With the highest values for TSC, TPC, TTC, TFC, and RSA, 'Real' shows superior antioxidant potential. This is reflected in its remarkable TPC of 388.8 mg/100 g, TTC of 274.5 mg/100 g, and RSA of 15.35%. These attributes indicate that 'Real' not only offers a rich supply of essential micronutrients but also possesses strong antioxidant properties that can contribute to reducing oxidative stress in the body. Given its high bioactive content, 'Real' could be marketed as a health-oriented product, appealing to consumers seeking strawberries with enhanced nutritional benefits. Similar to the results obtained by Antunes *et al*. (2010), the 'Real' exhibits exceptional values for key biochemical parameters, highlighting a high content of bioactive compounds with significant antioxidant properties.

Table 3. Biochemical parameters of strawberry cultivars

Cultivar	TSC (g 100 g $^{-1}$)	TPC (mg GAE 100 g $^{-1}$)	TTC (mg GAE 100 g $^{-1}$)	TFC (mg CE 100 g $^{-1}$)	TAC (mg C3-GE 100 g $^{-1}$)	RSA (%)
'Premial'	4.51±0.02 c*	234.06±0.36 e	157.56±0.25 f	50.93±1.03 e	18.85±0.08 d	6.67±0.03 b
'Coral'	4.86±0.03 b	363.65±1.08 b	267.93±0.56 b	69.98±1.24 b	18.77±0.09 d	4.84±0.02 c
'Real'	5.50±0.03 a	388.80±1.39 a	274.50±0.69 a	88.40±2.06 a	24.66±0.30 c	15.35±0.14 a
'Magic'	4.06±0.24 d	273.19±5.76 c	172.41±3.02 c	56.24±1.12 cd	27.25±3.08 b	6.92±0.67 b
'Floral'	3.83±0.20 e	247.39±3.06 d	168.66±1.77 d	55.05±2.07 cd	33.65±0.12 a	6.76±0.96 b
'Sarom'	3.20±0.02 f	238.11±0.41e	162.01±0.22 e	54.14±1.02 d	18.99±0.07 d	6.09±0.02 b
'Ireal'	3.36±0.02 f	221.69±3.68 f	135.37±0.27 g	57.40±0.96 c	19.05±0.08 d	2.22±0.04 d

*Differences between the means shown with the different letters in the same column are significant at the $p < 0.05$ level

In contrast to 'Real', the 'Ireal' shows the lowest values for several key bioactive compounds. Its TPC of 221.69 mg 100 g $^{-1}$ and TTC of 135.37 mg 100 g $^{-1}$ are the smallest among the cultivars analyzed. Furthermore, its RSA of just 2.22% suggests a limited antioxidant potential. Despite these lower values, 'Ireal' does contain a moderate level of flavonoid (57.4 mg 100 g $^{-1}$), which may still offer some health benefits, particularly in terms of anti-inflammatory and anti-cancer properties.

The cultivars 'Coral', 'Magic', and 'Floral' display more balanced biochemical profiles, with moderate levels of bioactive compounds. 'Coral 'stands out for its relatively high total phenolic content (363.65 mg 100 g $^{-1}$) and total flavonoid content (69.98 mg 100 g $^{-1}$), positioning it as a strong candidate for health-conscious markets.

The 'Sarom' cultivar, with a TPC of 238.11 mg 100 g $^{-1}$ and a moderate RSA of 6.09 %, falls into the mid-range of the cultivars studied.

Table 4 presents the colour characteristics of the seven strawberry cultivars. The cultivars show relatively similar L* values, ranging from 27.77 (for 'Floral') to 31.22 (for 'Real'). This suggests that all the cultivars have relatively light-coloured fruits, with only slight variations in lightness. 'Real' stands out with the highest lightness (31.22), making its fruit appear lighter compared to the others. With a C* of 33.12, the 'Sarom' has the most vivid and saturated colour. In contrast, the 'Magic' has the lowest C* (24.91), indicating lower intensity.

Table 4. Fruit colour parameters of strawberry cultivars

Cultivar	Brightness (L*)	Chroma Index (C*)	The hue angle (h°)
'Premial'	29.60 ± 0.30 a*	28.14 ± 4.41 ab	25.53 ± 4.19 a
'Coral'	30.90 ± 3.66 a	31.99 ± 3.85 ab	23.99 ± 3.44 a
'Real'	31.22 ± 1.19 a	30.15 ± 1.44 ab	26.23 ± 4.19 a
'Magic'	30.09 ± 4.09 a	24.91 ± 6.23 b	28.75 ± 1.43 a
'Floral'	27.77 ± 2.63 a	27.13 ± 2.81 ab	25.24 ± 1.07 a
'Sarom'	30.99 ± 0.71 a	33.12 ± 3.84 a	26.54 ± 3.23 a
'Ireal'	30.66 ± 1.01 a	30.66 ± 1.01 ab	27.52 ± 2.53 a

*Differences between the means shown with the different letters in the same column are significant at the $p < 0.05$ level

The h° values range from 23.99° (for 'Coral') to 28.75° (for 'Magic'), with relatively similar values across the cultivars. These angles indicate that the fruits of these cultivars are all in the red-to-pink spectrum, but with slight variations in hue. 'Coral' has the lowest h° (23.99°), which might indicate a slightly more orange or yellowish-red tint compared to the others. 'Magic', with a h° of 28.75°, appears to have a slightly different shade of red, potentially a more intense or slightly darker red than the others.

To explore potential correlations between the parameters in the dataset, we can examine how certain traits (like yield, berry weight, firmness, pH, and TSS) might relate to each other. Table 5 shows a strong positive correlation between production and weight. This suggests that either higher production leads to larger fruits, or the factors that promote higher yields also encourage heavier berry growth. There is a moderate positive correlation between production and fruit firmness. This indicates that firmer fruits tend to be associated with higher production. It is possible that factors promoting greater yields (such as growing conditions or plant grow) also help improve fruit firmness. Sweetness is less affected by size: there is no significant correlation between fruit or berry weight and total soluble solids, suggesting that fruit size does not necessarily correlate with sweetness. Other factors, such as environmental conditions, ripeness, and genetic traits, are more likely to influence sweetness. Firmness and pH have a strong positive relationship: firmer fruits tend to have higher pH values, indicating that texture and acidity are linked, possibly due to the stage of maturity of the fruit.

Table 5. Correlation of fruit parameters of strawberry cultivars

Parameters	Genotype	Production	Weight	Size Index	Firmness	pH	TSS
Production	0.124	1	-	-	-	-	-
Weight	0.413	**0.763****	1	-	-	-	-
Size Index	-0.166	0.016	-0.112	1	-	-	-
Firmness	**0.565****	**0.524***	**0.776****	0.070	1	-	-
pH	**0.487***	0.407	**0.521***	-0.192	**0.703****	1	-
TSS	-0.249	0.058	0.169	0.229	0.237	0.204	1

Pearson correlation; **. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed)

This research explores the key characteristics of the seven strawberry cultivars, examines the relationships between important fruit parameters and suggests ways to increase the yield of lower-yielding cultivars. The data on strawberry production reveals a mixture of advancements in agricultural techniques and climatic factors that have contributed to success in some regions. However, economic limitations and less favourable growing conditions remain significant challenges for others. For countries like Romania and Poland, learning from the best practices of leaders in the field such as the USA, Spain, and China could provide valuable pathways for improving both production and quality. By focusing on international collaboration, knowledge transfer, and investment in research and technology, these regions can overcome current challenges and strengthen their positions in the global strawberry market.

The 'Ireal' cultivar stands out due to its high yield per plant (0.69 kg), moderately high soluble solids content (9.97°Brix), and firmness, traits that enhance its potential for storage and transportation, and it is therefore a suitable choice for countries looking to increase their fruit production and improve quality. Its balanced performance in terms of both quantity and quality also makes it popular in commercial markets, where high production volumes and quality are essential.

Similarly, the 'Sarom' impresses with its large berry weight (24.2 g), high firmness (37.73 N), and a slightly higher pH (3.77), demonstrating that larger, firmer fruits can thrive in both commercial markets and align with consumer preferences for texture. Its high Chroma Index (33.12) further enhances its market appeal by indicating a visually appealing, vivid colour. In addition to its desirable size and texture, the 'Sarom' cultivar offers a good combination of physical and aesthetic qualities, making it highly suitable for markets that prioritize fruit appearance and texture alongside size. In contrast, cultivars like 'Floral' (with the lowest yield of 0.37 kg plant $^{-1}$) and 'Magic' (with lower TSS) may be less commercially viable due to their lower sweetness and firmness. These characteristics could make them less appealing to mass-market consumers who prioritize flavour and texture. However, these cultivars may find a niche market where factors such as taste or appearance are less critical than other aspects of strawberry production, offering potential for targeted sales in specific regions or consumer segments. The 'Real' cultivar stood out such an excellent candidate for fresh consumption, as well as for the development of functional foods and nutraceuticals. The biochemical diversity of strawberry cultivars highlights the importance of selecting the right variety to meet specific market demands. Understanding the biochemical attributes of each variety allows farmers and food processors to make informed decisions that align with consumer preferences and the intended use of the strawberries. Whether the focus is on antioxidant capacity, flavour, or processing suitability, this analysis highlights the importance of selecting cultivars that maximise nutritional value and market appeal. Strawberries are beloved globally, prized for their sweetness, aroma, and versatility. Beyond their delicious taste, they are rich in bioactive compounds that contribute to various health benefits, such as antioxidant, anti-inflammatory, and anti-cancer properties. The diverse biochemical profile of strawberries can vary significantly across cultivars, influencing not only their nutritional value but also their suitability for different uses in the food industry and beyond. A comprehensive analysis of biochemical parameters, including Total Sugar Content (TSC), Total Phenolic Content (TPC), Total Tannin Content (TTC), Total Flavonoid Content (TFC), Total Anthocyanin Content (TAC), and Radical Scavenging Activity (RSA), provides valuable insights into the strengths of different strawberry varieties.

For consumers prioritizing antioxidant activity, taste, and nutritional value, cultivars such as 'Real' and 'Coral' would be ideal. These varieties are rich in bioactive compounds and can support the growing demand for functional foods and nutraceuticals. However, for applications where processing stability and flavour balance are more important, cultivars like 'Magic' and 'Floral' may be more suitable. These cultivars offer moderate levels of bioactive compounds, contributing to good flavour, texture, and shelf life in processed products such as jams, syrups, and beverages. While they may not surpass 'Real' in terms of bioactive compound concentration, their balanced profiles make them suitable for a variety of consumer preferences and processing requirements. Its balanced biochemical composition suggests it may perform well in processing, offering consistent levels of key nutrients and antioxidants. Although it lags behind 'Real' in terms of antioxidant capacity, its moderate profile may still appeal to specific market niches.

In general, a pH level of around 3.5-4.0 is considered optimal for achieving a balanced strawberry flavour, indicating that the cultivars are within an acceptable range. Genotype has a significant role in determining the pH of the fruit. The soluble solids content is an important indicator of fruit sweetness and flavour, as it encompasses sugars and other soluble compounds. This suggests that breeding programs focusing on these traits could benefit from selecting for specific genotypes with desirable the soluble solids content and pH levels.

There may be an indirect relationship between the C* and the L* value. Cultivars with a higher C*, like 'Sarom', have more saturated colours, which could result in lighter colours (higher L* values). However, 'Magic', with its low C*, also has a moderate L* value, suggesting that colour intensity and lightness are not always directly correlated. The hue values do not show significant variation, but slight differences in h° indicate that cultivars such as 'Coral' and 'Magic' might appeal to consumers looking for fruits with subtle variations in red tones. Colour characteristics, such as L*, C*, and h°, help distinguish between the cultivars, providing insight into their visual appeal. Cultivars like 'Sarom' and 'Real' may be visually appealing due to their lightness and vibrancy.

Performance and quality of strawberry fruits: a comparative analysis of different cultivars

The comparative study of seven strawberry cultivars offers valuable insights into how various physical and chemical characteristics of fruits can influence both agricultural performance and commercial appeal. From plant yield to finer details regarding taste and color, each parameter plays a significant role in selecting the ideal cultivar under different growing conditions and consumer preferences (Sparacino *et al.*, 2024).

Variability in yield performance

One of the main aspects of this study is the significant variation in fruit yield among the cultivars. While 'Ireal' and 'Sarom' stand out with robust yields of 0.69 kg plant $^{-1}$ and 0.60 kg plant $^{-1}$, respectively, other cultivars like 'Floral' produce much less (0.37 kg plant $^{-1}$). This disparity suggests that factors such as genetics, growing conditions, and cultivation techniques can greatly impact the overall yield. However, a lower yield does not necessarily make a cultivar less valuable, as other attributes like taste, size, and color could appeal to different market segments.

Fruit size: balancing weight and aesthetics

Another critical factor that influences consumer preferences is fruit size (Sparacino *et al.*, 2024). In this study, the 'Sarom' cultivar stands out with an impressive fruit weight of 24.2 g, which is highly appealing to markets that favour larger, more substantial strawberries. This characteristic could also lead to higher market prices. On the other hand, cultivars like 'Premial', 'Coral', and 'Magic' have relatively smaller fruit weights (around 17-18 g), which may suit markets that value smaller, bite-sized fruits. However, size is not just about weight but also about proportion. 'Real' has a relatively high size index (1.51), meaning its fruits are more proportional in size and weight compared to other cultivars. This can be an advantage for those looking for a balance between fruit size and density.

Firmness: key to durability

Fruit firmness is an essential characteristic, especially when it comes to the longevity and transportability of strawberries (Sparacino *et al.*, 2024). Firmer fruits tend to last longer and are more resistant to handling, which is crucial for commercial distribution. Both 'Ireal' and 'Sarom' show high firmness values (36.03 N and 37.73 N, respectively), making them ideal for long-distance shipping and extended shelf life. In contrast, 'Real', with a lower firmness value of 16.83 N, may offer a more delicate taste but could have shorter shelf life and be more susceptible to damage. This could make them more prone to damage or quicker ripening, which might impact their commercial appeal.

Taste and sweetness: a deciding factor for consumers

Another deciding factor for consumer preference is sweetness (Oliver *et al.*, 2018), which is directly influenced by the total soluble solids (TSS) content. In this study, 'Coral' is the sweetest cultivar, with a TSS of 11.50°Brix, making it the most desirable for those seeking a sugary flavour. Conversely, 'Magic', with the lowest TSS (7.90°Brix), may have a more acidic and less sweet profile, which could be less appealing to those who prefer sweeter strawberries.

Fruit colour: a visual advantage

In a competitive market, the colour of strawberries plays an equally important role as taste (Sparacino *et al*., 2024). The C* and L* values indicate how vibrant and visually appealing the fruits are. Cultivars like 'Sarom' and 'Real' have high C* values, suggesting they are more intensely coloured and therefore more attractive to consumers. The L* values, which indicate lightness, show that all cultivars have relatively light-coloured fruits, but with subtle differences that could make them stand out in the marketplace. The h° refers to the dominant colour tone of the fruit. It is a measure of the colour's position in the spectrum (0° is red, 90° is yellow, 180° is green, and 270° is blue). In this case, all the cultivars fall within the reddish range, as is typical for strawberries.

Choosing the optimal cultivar depending on context

The choice of the ideal strawberry cultivar depends on a variety of factors, ranging from plant yield to physical and chemical fruit characteristics (Cocco *et al*., 2015; Cervantes *et al*., 2020; Costa *et al*., 2025). Cultivars like 'Ireal' and 'Sarom' are excellent choices for those looking for high yields and firm fruits, while 'Coral' might attract consumers who prefer sweeter strawberries. 'Magic' could appeal to those who favour denser, more compact fruits, while 'Real' may be the perfect balance of size and firmness.

This study highlights the complexity of selecting a strawberry cultivar considering market demands, environmental conditions, and consumer preferences. Each cultivar has its own advantages, whether for local markets, long-distance exports, or producing visually appealing, sweet fruit. This makes the decision-making process multifaceted and nuanced.

Conclusions

Strawberry breeding aims to meet market demands by obtaining larger fruits and color uniformity. The quality of strawberry fruits is based on the determined hereditary basis of the variety. Based on this evaluation of seven strawberry cultivars bred in Romania, highlights differences regarding yield, firmness, sweetness, and biochemical composition resulting 'Ireal' and 'Sarom' showed the highest yields, but 'Sarom' also had the largest berry weight and highest firmness, while 'Coral' stood out for its sweetness. The biochemical diversity of strawberry cultivars highlights the importance of selecting the right variety. 'Real' shows superior antioxidant potential, noting highest biochemical content for all analyzed parameters. In the future, based on remarkable data of these strawberry assays, the cultivars 'Sarom' and 'Ireal' can be recommended for growers, breeders or markets from Romania, as well in other regions with similar environmental conditions. These insights can help guide future strawberry breeding programs, improve fruit quality, and optimize cultivation practices for desirable traits like firmness, pH, and berry size. The breeding value of the new strawberry varieties appears promising in Romanian climate, regarding yield and fruit quality.

Authors' Contributions

Conceptualization: OH, MS; Data curation: MS, LEV; Formal analysis: OH, MS; Funding acquisition: MS; Investigation: MS, OH, LEV; Methodology: MS, MM; Project administration: MS; Resources: MS; Software: OH, MS, LEV; Visualization: MS, MM; Writing - original draft: OH; Writing - review and editing: MS, LEV.

All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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